

**Measurements of the Thermal Conductivity of HFC-143a in the Temperature Range
from 300 to 500 K at Pressures up to 50 MPa¹**

B. Le Neindre^{1,2} Y. Garrabos³ and M. S. Kim⁴

¹ L.I.M.H.P.- C.N.R.S., Institut Galilée, Université Paris Nord, Av. J. B. Clément,
93430 Villetaneuse, France

² To whom the correspondence should be addressed.

³ Institut de Chimie de la Matière Condensée de Bordeaux, Université de Bordeaux 1,
Av. du Dr. Schweitzer, 33608 Pessac, France.

⁴ Department of Mechanical Engineering, Seoul National University, Seoul 151-742,
Korea

ABSTRACT

Measurements of the thermal conductivity of HFC-143a that have been made by a coaxial cylinder cell operating in steady state are reported. The measurements of the thermal conductivity of HFC-143a were performed along several quasi-isotherms between 300 and 500 K in the gas phase and the liquid phase. The pressure range covered varies from 0.1 to 50 MPa. Based on the measurement of more than 600 points, an empirical equation is provided to describe the thermal conductivity outside the critical region as a function of temperature and density. A careful analysis of the various sources of error leads to an estimated uncertainty of approximately $\pm 1.5\%$

KEY WORDS: coaxial cylinders, high pressure, refrigerants, HFC-143a, thermal conductivity,

1. INTRODUCTION

Recently the thermophysical properties of HFC-143a (1,1,1-trifluoroethane) were investigated widely since this hydrofluorocarbon in combination with pentafluoroethane (HFC-125) and/or 1,1,1,2-tetrafluoroethane (HFC-134a), is expected to be an environmentally acceptable alternative to the refrigerant HCFC-22 (chlorodifluoromethane), used in refrigeration, heat pumps and air-conditioning equipment. There are very few measurements of transport properties of HFC-143a, if we compare to other refrigerants. The thermal conductivity of HFC-143a was measured in a vertical coaxial cylinder cell, operating in the steady-state mode. We have studied the influence of temperature and pressure on the thermal conductivity. The measurements were performed to make an analysis of the data based on the residual concept. The thermal conductivity $\lambda(T,\rho)$ is a function of temperature T and density ρ that may be represented as the sum of three terms :

$$\lambda(T,\rho) = \lambda_0(T) + \delta\lambda(T,\rho) + \Delta\lambda(T,\rho), \quad (1)$$

where $\lambda_0(T)$ is the dilute gas thermal conductivity, $\delta\lambda(T,\rho)$ is the residual thermal conductivity, and $\Delta\lambda(T,\rho)$ is the critical enhancement. The dilute gas contribution $\lambda_0(T)$ was obtained by performing measurements at atmospheric pressure as a function of temperature. The background term,

$$\lambda_B(T,\rho) = \lambda_0(T) + \Delta\lambda(T,\rho), \quad (2)$$

was obtained by making measurements along quasi-isotherms as a function of pressure in the liquid phase and in the gas phase far away from the critical region. The remaining contribution $\Delta\lambda(T,\rho)$, represents the enhancement of the thermal conductivity due to critical fluctuations, and becomes significant in the supercritical region or in the subcritical region along the saturation curve. In this paper, we report only experimental data in the liquid phase and in the gas phase far away from the critical point in order to determine the so-called thermal conductivity background. Our measurements in the critical region and in the gas phase below the critical point will be reported later. The density was calculated with an equation of state reported by Outcalt and McLinden [1] where the critical parameters are given as follows :

$$T_c = 346.04 \text{ K},$$

$$p_c = 3.7756 \text{ MPa, and}$$

$$\rho_c = 432.9 \text{ kg}\cdot\text{m}^{-3}$$

2. EXPERIMENTAL APPARATUS

The thermal conductivity of HFC-143a was measured using vertical coaxial cylinders operating in the steady-state mode. The same device was already used in the measurements of the thermal conductivity of 1-chloro-1,1-difluoroethane (HCFC-142b) [2], pentafluoroethane (HFC-125) [3] and 1,1,1,2-tetrafluoroethane (HFC-134a) [4]. A detailed description of the cell and of the method of measurement is available [5]. The sample was provided by Elf-Atochem, and its purity was estimated to be better than 99.5% by the manufacturers' analysis.

3. DILUTE-GAS THERMAL CONDUCTIVITY

The results of the measurements of the thermal conductivity at atmospheric pressure are listed as a function of temperature in Table I. The experimental data were fitted by a linear equation :

$$\lambda_o = -18.59 + 0.10723 T \quad (3)$$

Figure 1 shows the deviations between our experimental data measured at atmospheric pressure and Eq. (3), there are within 1.5 %, there are always smaller than the experimental uncertainties. Figure 2 shows the deviations of the data of Hammerschmidt [6] and Tanaka et al. [7] from Eq. (3). There data are always smaller than the corresponding values calculated by Eq. (3). The deviations are large for the two sets of data, and they increase when the temperature rises, they reach respectively - 18 % at 418 K and - 13 % at 353 K.

The temperature dependence of the thermal conductivity of the dilute gas can be represented by an expression derived from the kinetic theory of gases. The thermal conductivity is related to the reduced effective collision cross sections which contain all the contributions of translational, rotational, vibrational, and electronic degrees of freedom. As there is a lack of reliable experimental data on the vibrational collision number, we used for the calculation of the thermal conductivity in the zero density the practical engineering form :

$$\lambda_o(T) = \frac{0.177568(T/M)^{0.5} C_p^o / R}{\sigma^2 \Omega_\lambda^*(T^*)}, \quad (4)$$

where, M is the molar mass in $\text{kg}\cdot\text{kmol}^{-1}$, T the absolute temperature, $\Omega_\lambda^*(T^*)$ the reduced effective collision cross-section for thermal conductivity, C_p^o the ideal isobaric heat capacity and R the gas constant. The reduced temperature is given by $T^* = kT/\varepsilon$, where k is Boltzmann's constant.

On the other hand the low pressure gas viscosity can also be represented by the Chapman-Enskog equation derived from the kinetic theory of gases :

$$\eta_o(T) = \frac{0.026693(TM)^{0.5}}{\sigma^2 \Omega_\eta^*(T^*)}, \quad (5)$$

where $\Omega_\eta^*(T^*)$ is the reduced effective collision cross-section for viscosity. Some authors consider high order correction factors for thermal conductivity f_λ and viscosity f_η . In fact, we have found that the inclusion of these terms do not improve significantly the fits and complicate the analysis of the data.

The scaling factors σ and ε/k , which correspond to the effective Lennard-Jones 12-6 potential parameters, were determined by a regression analysis of both viscosity and thermal conductivity data at atmospheric pressure. For this purpose the experimental viscosity data (in $\mu\text{Pa s}$) of Takahashi et al. [8] near atmospheric pressure were represented by a linear equation :

$$\eta_o = -0.1644 + 0.03829 T. \quad (6)$$

In order to carry on the calculations, the ideal specific heat at constant pressure was calculated from the data reported by Yokozeki et al. [9] :

$$\frac{C_p^o}{R} = \sum_{i=0}^6 c_i T^i, \quad (7)$$

where

$$\begin{aligned} c_0 &= 2.912897, & c_1 &= 1.448316 \times 10^{-2}, \\ c_2 &= 6.678891 \times 10^{-5}, & c_3 &= -8.24828 \times 10^{-7}, \\ c_4 &= 2.663593 \times 10^{-10}, & c_5 &= -1.668859 \times 10^{-13}, \\ c_6 &= 4.189036 \times 10^{-17}, & & \\ R &= 8.314471 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1} & & \end{aligned}$$

The reduced collision integral Ω_λ^* was estimated as a function of reduced temperature, $T^* = kT / \varepsilon$, using a functional expansion :

$$\Omega_\lambda^* = \sum_{j=1}^3 A_j (1/T^*)^j, \quad (8)$$

where

$$A_1 = 0.444358, \quad A_2 = 0.327867, \quad A_3 = 0.1936835.$$

For the collision integral of the viscosity, we have used the following equation reported by Kestin et al. [10]

$$\Omega_\eta^* = \exp \left[0.46641 + \sum_{j=1}^4 B_j \ln(T^*)^j \right], \quad (9)$$

where

$$B_1 = -0.56991, \quad B_2 = 0.19591,$$

$$B_3 = -0.03879, \quad B_4 = 0.00259$$

The best agreement between experimental data of thermal conductivity and viscosity, and calculated values by the corresponding theoretical equations (Eq. (4) and Eq. (5)) , was found for $\varepsilon / k = 300$ K and $\sigma = 0.480$ nm. The average deviations are of the order of $\pm 2\%$ in the respective temperature ranges of experiments. In fact, it is always feasible to improve the agreement between experimental data and corresponding values calculated by theoretical equations. For viscosity, for instance, with the set of potential parameters $\varepsilon / k = 290$ K and $\sigma = 0.4885$ nm the maximum deviation is less than $\pm 0.5\%$, but for thermal conductivity the maximum deviation increases up to $\pm 4\%$. The analysis of transport properties at atmospheric pressure of refrigerants that we have studied up to now, leads to the same conclusion. It is possible to calculate the thermal conductivity and the viscosity at low density using Chapman-Enskog equations and appropriated potential parameters with an average deviation of the order of $\pm 2\%$ with respect to experimental data. The relative deviations of the present experimental thermal conductivity data from their optimal representation by Eq. (4), Eq. (7) and Eq. (8) are shown in Fig. 3. The relative deviations between the calculated

values of viscosity (Eq. (5) and Eq. (9)) and the data of Takahashi et al. are shown in Fig. 4. The percentage deviations between theoretical thermal conductivity values calculated by Eqs. (4,8,9) and calculated data by Eq. (3) increase up to $\pm 3\%$ at 600 K and $\pm 6\%$ at 900 K. For the viscosity, the percentage deviations between calculated values using the potential parameters and Eq. (5) and Eq. (9) and extrapolated experimental data fitted by Eq. (6) reach $\pm 3.3\%$ at 600 K and $\pm 13\%$ at 900 K. In fact, the agreement with the theory is very satisfactory for viscosity and thermal conductivity in the temperature range where experimental data are available.

4. DENSE FLUID THERMAL CONDUCTIVITY

In order to determine the excess function or the residual term of the thermal conductivity $\delta\lambda(\rho,T)$, we have performed measurements in the liquid phase and in the supercritical gas phase, far away from the critical region, along eleven quasi-isotherms at 306.3, 317.2, 336.5, 348.0, 375.7, 395.1, 414.9, 434.3, 453.8, 473.7, and 498.3 K. For the high density and low temperature range, we used also the experimental data of Kim et al. [11] The residual function for the thermal conductivity has been represented by a six-order polynomial of the form,

$$\frac{\delta\lambda}{\Lambda_c} = \sum_{i=1}^6 b_i \left(\frac{\rho}{\rho_c} \right)^i, \quad (10)$$

where $\rho_c = 432.9 \text{ kg}\cdot\text{m}^{-3}$ is the critical density, and the coefficients b_i in Eq.(10) are

$$b_1 = 0.144465, \quad b_2 = 3.60601$$

$$b_3 = -7.3279, \quad b_4 = 7.76065,$$

$$b_5 = -4.176, \quad b_6 = 1.10242$$

$$b_7 = -0.111749$$

$$\text{and } \Lambda_c = 16.8 \text{ mW}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$$

The excess function of the thermal conductivity is represented as a function of density in figure 5 along six quasi isotherms. The comparison with the experimental measurements of Yata et al. [12] in the temperature range 268-314 K, and the pressure range 2.4-30.7 MPa, shows that their data are lower than the corresponding values calculated values by the background equation (Eq. 2), the relative deviations vary from $\pm 0\%$ to $\pm 6\%$ in the density range 890 to 1150 kg·m⁻³. Figure 6 shows the relative deviations between calculated values by the background equation (2) and the experimental data of Yata as a function of density.

5. CONCLUSION

New measurements of the thermal conductivity of HFC-143a are presented in the temperature range from 300 to 500 K along eleven quasi-isotherms and at pressures up to 50 MPa, with an estimated uncertainty of $\pm 1.5\%$. At atmospheric pressure, if large discrepancies are observed with available experimental data, a good agreement is found with the dilute gas theory of Chapman-Enskog. A background equation was determined which can be used to calculate the thermal conductivity from 260 to 600 K and up to a density of 1150 kg·m⁻³, with an uncertainty of $\pm 3\%$. It is obvious that in the critical region a supplementary functional form must be added to take into account the critical enhancement.

ACKNOWLEDGMENT

We are indebted to ATOCHEM for providing us HFC-143a samples.

REFERENCES

1. S. L. Outcalt and M. O. McLinden, *Int. J. Thermophys.* **18** : 1448 (1997).
2. A. T. Sousa, P.S. Fialho, C.A. Nieto de Castro, R. Tufeu, and B. Le Neindre, *Int. J. Thermophys.* **13** : 363 (1992).
3. B. Le Neindre and Y. Garrabos, *Int. J. Thermophys.* **20** : 375 (1999).
4. B. Le Neindre and Y. Garrabos, *Int. J. Thermophys.* **20** : 1379 (1999).
5. B. Le Neindre and R. Tufeu, Measurements of the Thermal Conductivity of Fluids by the Coaxial Cylinder Method, in *Experimental Thermodynamics III, Measurements of the Transport Properties of Fluids*, W.A. Wakeham, A. Nagashima, and J.V. Sengers, eds (Blackwell, Oxford, 1991), pp. 111-142
6. U. Hammerschmidt, *Int. J. Thermophys.* **16** : 1203 (1995).
7. Y. Tanaka, M. Nakata, and T Makita *Int. J. Thermophys.* **12** : 949 (1991).
8. Y. Takahashi, N. Shibasaki-Kitakawa, and C. Yokoyama *Int. J. Thermophys.* **20** : 435 (1999).
9. A. Yokozeki, H. Sato, and K. Watanabe, *Int. J. Thermophys.* **19** : 89 (1998).
10. J. Kestin, K. Knierim, E. A. Mason, B. Najafi, S. T. Ro, and M. Waldam, *J. Phys. Chem. Ref. Data* **13** :229 (1984)
11. M. S. Kim, private communication
12. J. Yata, M. Hori, K. Kobayashi, and T. Minamiyama, *Int. J. Thermophys.* **17** : 561 (1996).

Table I : The Thermal Conductivity of HFC-143a at Atmospheric Pressure

T (K)	λ (mW•m ⁻¹ •K ⁻¹)	T (K)	λ (mW•m ⁻¹ •K ⁻¹)	T (K)	λ (mW•m ⁻¹ •K ⁻¹)
299.17	13.62	329.08	16.53	377.26	21.70
301.96	13.83	335.10	17.42	377.29	21.74
302.29	13.86	340.88	18.17	396.28	24.18
306.79	14.38	342.63	18.29	407.57	24.96
307.45	14.48	343.22	18.36	416.02	25.72
309.33	14.57	343.24	18.15	435.05	27.99
311.74	14.82	353.40	19.09	454.71	30.15
324.25	16.03	355.89	19.73	474.42	32.23
324.55	16.08	356.75	19.61	484.42	33.61
327.58	16.43	356.76	19.43	499.02	34.95
328.63	16.51	377.02	21.85		

Table II : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 306.3 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
307.13	.55	19.83	14.57
306.63	.541	19.51	14.68
306.46	1.05	42.24	14.86
305.62	1.044	42.15	15.29
305.62	1.145	47.46	15.33
305.62	1.184	49.60	15.36
305.61	1.191	50.00	15.40
305.61	1.26	53.95	15.48
305.60	1.291	55.79	15.54
305.60	1.303	56.52	15.57
305.60	1.365	60.37	15.62
305.10	1.371	61.03	15.73
305.10	1.382	61.74	15.86
305.09	1.383	61.80	15.94
305.09	1.384	61.87	15.99
304.92	1.385	62.03	16.05
304.92	1.386	62.10	16.10
304.43	1.387	62.44	16.12
304.43	1.392	62.78	16.13
304.69	3	919.94	68.26
304.68	4	929.90	69.39
304.82	5.056	938.80	70.52
304.99	5.046	938.07	70.46
304.98	6	946.04	71.29
304.97	7	953.80	72.16
304.96	8	961.04	73.06
304.95	9	967.85	73.98
305.26	10.021	973.37	75.02
305.25	11	979.37	76.08

305.24	12	985.20	76.87
305.23	13	990.77	77.79
305.22	14	996.09	78.40
305.54	15.113	1000.85	78.93
305.54	16	1005.22	79.76
305.53	17	1009.97	80.40
305.52	18	1014.56	80.94
305.52	19	1018.99	81.52
305.51	19.978	1023.19	82.17
305.51	21	1027.45	82.70
305.50	22	1031.49	83.30
305.50	23	1035.42	83.89
305.49	24	1039.24	84.59
305.65	25.052	1042.77	85.21
305.48	26	1046.59	85.62
305.48	27	1050.12	86.12
305.48	28	1053.57	86.62
305.47	29	1056.94	87.39
305.47	30.038	1060.36	88.03
305.46	31	1063.46	88.43
305.62	32	1066.27	89.01
305.62	33	1069.36	89.54
305.61	34	1072.40	90.10
305.61	35.007	1075.39	90.83
305.60	36	1078.28	91.20
305.60	37	1081.15	91.90
305.59	38	1083.95	92.47
305.59	39	1086.71	93.19
305.59	39.779	1088.82	93.19
305.58	39.87	1089.07	94.11
305.58	40	1089.42	93.78
305.58	41.027	1092.15	94.52

305.58	41.995	1094.68	95.13
305.58	43.038	1097.36	95.59
305.58	44.117	1100.09	96.33
305.56	45.23	1102.85	96.98
305.56	46.003	1104.74	97.62
305.56	47.120	1107.43	98.10
305.55	48.042	1109.63	98.75

Table III : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 317.2 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
317.00	2.481	849.77	63.02
316.99	3	858.85	63.70
316.97	3.903	872.66	64.83
317.27	5	885.58	66.10
317.41	6.023	896.71	67.30
317.40	7	906.84	68.25
317.38	7.959	915.90	69.23
317.37	9	924.95	70.15
317.36	10.016	933.12	71.20
317.35	11	940.52	72.06
317.34	12	947.59	72.95
317.33	13	954.26	73.80
317.32	14.073	961.03	74.72
317.31	15	966.60	75.66
317.30	16	972.35	76.42
317.29	17	977.84	77.20
317.29	18.1	983.63	77.78
317.28	19	988.19	78.44
317.27	20	993.07	79.15
317.27	21	997.79	79.78
317.27	22.13	1002.92	80.54
317.26	23	1006.76	81.27
317.26	24	1011.04	81.82
317.25	25	1015.19	82.51
317.24	26.148	1019.80	83.10
317.24	27	1023.14	83.53
317.23	28	1026.96	84.11
317.23	29	1030.68	84.75

317.22	30.235	1035.15	85.59
317.23	31	1037.86	86.04
317.23	32	1041.31	86.41
317.21	33	1044.69	87.03
317.23	34.255	1048.83	87.76
317.20	35	1051.24	88.05
317.20	36	1054.40	88.56
317.20	37	1057.50	89.08
317.19	38.4	1061.74	89.91
317.19	39	1063.52	90.27
317.19	40	1066.46	91.08
317.18	41.4	1070.46	91.54
317.18	42	1072.15	91.81
317.18	43	1074.92	92.37
317.17	44.3	1078.44	92.82
317.17	45	1080.31	93.21
317.16	46	1082.94	93.79
317.16	47	1085.52	94.37
317.156	48	1088.07	94.95
317.156	49	1090.58	95.55
317.14	50	1093.05	96.15

Table IV : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 336.5 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
336.19	3.551	731.78	56.48
336.18	4.015	752.02	57.22
336.16	4.501	768.60	58.26
336.14	5	782.67	59.23
336.11	7	823.51	61.09
336.09	7.730	835.01	62.90
336.07	8.911	851.18	64.30
336.49	9.994	862.37	65.72
336.92	11.011	871.72	66.50
336.91	12.2	883.47	67.51
336.90	13.007	890.83	68.60
336.89	14.057	899.78	69.52
336.88	14.915	906.64	70.46
336.87	16.008	914.85	71.27
336.85	16.987	921.80	72.21
336.85	18.031	928.80	72.90
336.85	18.031	928.80	73.01
336.84	19.012	935.07	73.85
336.83	19.944	940.75	74.46
336.82	21.017	947.02	75.28
336.81	22.005	952.54	76.11
336.81	23.008	957.93	76.76
336.80	23.997	963.04	77.33
336.79	24.909	967.61	78.02
336.78	26.027	973.01	78.69
336.78	27.010	977.59	79.29
336.77	28.014	982.13	79.92
336.77	29.015	986.52	80.52
336.77	30.012	990.76	81.17

336.76	31.011	994.89	81.74
336.76	32.005	998.89	82.21
336.75	32.972	1002.69	82.86
336.75	34.003	1006.64	83.35
336.74	34.93	1010.10	84.12
336.74	36.002	1014.01	84.67
336.73	36.997	1017.54	85.19
336.73	37.979	1020.96	85.77
336.72	39.021	1024.50	86.33
336.72	40.393	1029.05	87.16
336.71	41.007	1031.05	87.78
336.71	41.995	1034.20	88.33
336.70	43.012	1037.39	88.80
336.70	44.027	1040.50	89.51
336.69	45.033	1043.54	90.21

Table V : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 348.0 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
348.11	10.002	814.23	62.43
348.10	10.987	827.87	63.66
348.09	12.051	840.98	64.72
348.08	13.016	851.73	65.81
348.08	14.003	861.81	66.79
348.07	15.122	872.34	68.11
348.06	16.007	880.07	68.77
348.06	16.955	887.88	69.85
348.05	18.012	896.05	70.46
348.05	19.037	903.53	71.44
348.05	20.013	910.28	72.10
348.04	21.022	916.92	72.76
348.04	22.036	923.29	73.63
348.03	23.042	929.33	74.40
348.03	24.097	935.41	75.24
348.02	25.093	940.91	76.35
348.02	25.972	945.60	77.06
348.02	27.189	951.85	77.34
348.02	28.013	955.93	78.14
348.01	29.045	960.89	78.64
348.01	30.140	965.98	79.38
348.01	31.006	969.88	79.96
348.01	31.948	974.02	80.49
348.00	33.017	978.58	81.12
348.00	33.779	981.74	81.45
348.00	34.947	986.48	82.39
348.00	36.012	990.66	82.82
348.00	37.131	994.96	83.39
347.99	38.035	998.35	83.84

347.99	38.979	1001.79	84.32
347.99	40.122	1005.87	84.87
347.98	41.23	1009.74	85.77
347.98	42.053	1012.55	86.03
347.98	43.017	1015.77	86.26
347.98	44.012	1019.03	86.50
347.98	44.831	1021.67	86.77
347.98	46.007	1025.39	87.94
347.97	47.043	1028.59	88.23
347.97	48.002	1031.50	88.44

Table VI : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 375.7 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
377.26	.1	2.71	21.70
377.25	.5	13.92	21.96
377.10	1	29.00	22.36
377.07	1.5	45.47	22.85
376.91	2	63.69	23.35
376.89	2.5	84.00	23.96
376.18	3	107.50	24.85
375.72	3.5	134.81	26.14
375.52	4	167.21	27.99
375.05	4.5	208.15	30.39
374.83	5	260.75	33.61
374.60	5.5	330.62	38.41
374.52	6	410.80	43.33
374.48	6.5	482.42	46.33
374.46	7	536.65	48.64
374.44	7.5	576.67	50.51
374.42	8	607.26	51.74
374.41	8.5	631.77	52.92
374.40	9	652.12	53.86
374.39	9.5	669.52	54.78
374.39	10	684.72	55.65
374.38	11	710.41	56.94
374.36	12	731.69	58.43
374.36	13	749.89	59.52
374.35	14	765.83	60.68
374.34	15	780.06	61.86
374.33	16	792.91	62.83
374.33	17	804.64	63.84
374.32	18	815.47	65.14

374.31	19	825.49	65.91
374.31	20	834.85	66.56
374.30	21	843.64	67.45
375.11	22	849.68	68.60
375.10	23	857.58	69.49
375.10	24	865.08	70.40
375.09	25	872.20	71.18
375.09	26	879.01	71.81
374.28	27	887.49	72.34
375.08	28	891.77	73.12
375.08	29	897.76	73.78
375.07	30	903.53	74.47
375.07	31	909.11	75.16
375.07	32	914.48	75.87
375.07	33	919.68	76.40
375.06	34	924.70	76.95
374.25	35	931.29	77.38
374.25	36	936.00	77.94
375.06	37	938.91	78.63
375.05	38	943.38	79.21
375.05	39	947.72	79.80
375.05	40	951.97	80.39
375.05	41	956.09	80.79
375.04	42	960.12	81.20
374.23	43	965.59	81.48
374.23	44	969.41	81.89
375.04	45	971.64	82.44

Table VII : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 395.1 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
396.28	.1	2.57	24.18
396.27	.5	13.17	24.46
396.26	1	27.23	24.82
396.24	1.5	42.31	25.22
396.22	2	58.60	25.63
395.69	2.5	76.46	26.14
395.66	3	95.86	26.74
395.24	3.5	117.49	27.67
395.21	4	141.30	28.77
394.78	4.5	168.49	30.17
394.74	5	198.70	31.72
394.58	5.5	233.21	32.97
394.39	6	272.48	35.89
394.21	6.5	316.16	38.49
394.17	7	361.87	41.09
394.13	7.5	407.15	43.68
394.10	8	449.12	45.72
394.08	8.5	486.27	47.67
394.07	9	518.38	48.96
394.05	9.5	546.00	50.19
394.04	10	569.88	51.48
394.02	11	609.08	53.36
394.00	12	640.22	55.20
393.99	13	665.91	56.76
393.98	14	687.74	58.23
393.97	15	706.72	59.24
393.96	16	723.52	60.66
393.96	17	738.59	61.67
393.95	18	752.27	62.62

393.94	19	764.80	63.60
393.94	20	776.36	64.36
393.93	21	787.10	65.14
393.93	22	797.14	65.83
393.92	23	806.56	66.92
393.92	24	815.44	67.61
393.91	25	823.84	68.32
393.91	26	831.81	69.05
393.91	27	839.40	69.79
393.90	28	846.65	70.54
393.90	29	853.57	71.00
393.89	30	860.21	71.78
393.89	31	866.59	72.42
393.89	32	872.72	73.07
393.88	33	878.63	73.73
393.88	34	884.35	74.40
393.88	35	889.86	75.18
393.88	36	895.20	75.60
393.87	37	900.36	76.13
393.87	38	905.38	76.75
393.87	39	910.25	77.29
393.87	40	914.99	77.84
393.86	41	919.58	78.40
393.86	42	924.06	78.97
393.86	43	928.43	79.54
393.86	44	932.70	79.93
393.86	45	936.85	80.32

Table VIII : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 414.9 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
416.02	.1	2.45	25.72
416.01	.5	12.48	26.02
415.99	1	25.65	26.52
415.97	1.5	39.60	27.04
415.95	2	54.42	27.57
415.31	2.5	70.38	28.12
415.29	3	87.33	28.73
415.02	3.5	105.62	29.41
414.75	4	125.36	30.03
414.73	4.5	146.48	30.69
414.45	5	169.53	31.80
414.17	5.5	194.50	33.01
414.01	6	221.28	34.60
413.85	6.5	250.00	36.03
413.84	7	280.10	36.97
413.55	7.5	312.36	38.98
413.52	8	344.45	40.79
413.37	8.5	376.82	42.51
413.22	9	408.17	44.20
413.20	9.5	437.18	45.71
413.19	10	464.03	46.97
413.16	11	511.02	48.90
413.15	12	549.96	50.67
413.13	13	582.49	52.83
413.11	14	610.05	54.43
413.10	15	633.83	55.93
413.09	16	654.65	57.01
413.09	17	673.18	58.13
413.07	18	689.82	58.97

413.07	19	704.94	59.89
413.06	20	718.78	60.79
413.06	21	731.55	61.65
413.81	22	741.28	62.89
413.80	23	752.41	63.87
413.79	24	762.84	64.88
413.79	25	772.65	65.79
413.78	26	781.92	66.59
413.78	27	790.70	67.41
413.77	28	799.04	68.25
413.77	29	807.00	69.11
413.76	30	814.60	69.91
413.76	31	821.87	70.51
413.76	32	828.85	71.11
413.75	33	835.54	71.89
413.75	34	842.00	72.56
413.75	35	848.22	73.17
413.74	36	854.22	73.82
413.74	37	860.02	74.49
413.74	38	865.63	75.00
413.74	39	871.07	75.51
413.74	40	876.34	76.03
413.73	41	881.46	76.56
413.73	42	886.43	77.10
413.73	43	891.27	77.64
413.72	44	895.99	78.19
413.72	45	900.57	78.75

Table IX : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 434.3K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
435.05	.1	2.34	27.99
435.04	.5	11.88	28.33
435.03	1	24.32	28.72
435.02	1.5	37.36	29.18
435.00	2	51.06	29.62
434.63	2.5	65.56	30.01
434.61	3	80.77	30.50
434.36	3.5	96.92	30.98
434.34	4	113.89	31.56
434.32	4.5	131.80	32.34
434.06	5	150.88	33.15
434.04	5.5	170.81	34.00
433.78	6	192.01	34.74
433.63	6.5	214.13	35.88
433.61	7	237.00	36.96
433.47	7.5	260.86	38.07
433.45	8	285.10	39.22
433.43	8.5	309.67	40.41
433.43	9	334.26	41.70
433.40	9.5	358.57	42.81
433.26	10	382.67	43.88
433.24	11	427.36	45.98
433.22	12	467.48	47.96
433.20	13	502.83	49.94
433.18	14	533.82	51.50
433.17	15	561.07	53.01
433.15	16	585.19	54.51
433.14	17	606.70	55.81
433.13	18	626.05	56.88

433.13	19	643.60	57.99
433.12	20	659.65	59.13
433.11	21	674.40	60.25
433.10	22	688.05	61.20
433.10	23	700.75	62.13
433.09	24	712.62	62.96
433.09	25	723.75	63.81
433.08	26	734.24	64.56
433.08	27	744.15	65.32
433.07	28	753.55	66.24
433.07	29	762.48	67.04
433.55	30	769.90	68.34
433.55	31	778.04	68.90
433.55	32	785.84	69.48
433.54	33	793.32	70.06
433.54	34	800.51	70.66
433.54	35	807.42	71.26
433.54	36	814.07	71.87
433.53	37	820.49	72.50
433.53	38	826.70	73.14
433.52	39	832.70	73.78
433.52	40	838.52	74.44
433.52	41	844.15	74.94
433.52	42	849.62	75.45
433.52	43	854.93	75.96
433.51	44	860.09	76.48
433.51	45	865.12	77.01

Table X : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 453.8 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
454.71	.1	2.24	30.15
454.71	.5	11.33	30.41
454.70	1	23.10	30.68
454.69	1.5	35.35	30.99
454.68	2	48.10	31.39
454.43	2.5	61.43	31.82
454.42	3	75.30	32.28
454.41	3.5	89.76	32.82
454.16	4	104.93	33.29
454.15	4.5	120.67	33.86
454.02	5	137.11	34.33
454.13	5.5	154.04	35.00
455.00	6	171.76	35.63
453.74	6.5	190.22	36.40
453.61	7	209.14	37.15
453.46	7.5	228.59	38.93
453.46	8	248.24	38.89
453.44	8.5	268.18	39.91
453.31	9	288.49	40.83
453.30	9.5	308.60	41.85
453.28	10	328.57	42.84
453.14	11	367.78	44.63
453.00	12	404.92	46.49
452.98	13	439.00	48.07
452.97	14	470.10	49.59
452.95	15	498.28	51.15
452.94	16	523.79	52.56
452.93	17	546.90	53.95
452.91	18	567.93	55.23

452.91	19	587.14	56.36
452.90	20	604.78	57.44
452.89	21	621.05	58.58
452.88	22	636.12	59.43
452.88	23	650.16	60.30
452.87	24	663.28	61.30
452.86	25	675.58	62.11
452.86	26	687.17	63.06
452.85	27	698.11	63.77
452.85	28	708.48	64.92
452.84	29	718.32	65.69
452.84	30	727.69	66.66
452.83	31	736.63	67.58
452.83	32	745.17	68.17
452.83	33	753.35	68.88
452.82	34	761.20	69.60
452.82	35	768.75	70.30
452.82	36	776.01	70.90
452.81	37	783.01	71.51
452.81	38	789.76	72.09
452.81	39	796.29	72.72
452.80	40	802.60	73.22
452.80	41	808.72	73.70
452.80	42	814.64	74.19
452.80	43	820.40	74.69
452.80	44	825.98	75.20
452.79	45	831.42	75.71

Table XI : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 473.7 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
474.42	.1	2.14	32.23
474.42	.5	10.82	32.43
474.41	1	22.01	32.67
474.41	1.5	33.57	32.94
474.40	2	45.52	33.25
474.28	2.5	57.90	33.67
474.39	3	70.67	34.04
474.38	3.5	83.90	34.48
474.01	4	97.69	34.96
473.65	4.5	111.98	35.41
473.64	5	126.60	35.93
473.52	5.5	141.72	36.46
473.39	6	157.27	37.01
473.26	6.5	173.25	37.60
473.25	7	189.49	38.18
473.24	7.5	206.04	38.83
473.23	8	222.84	39.53
473.22	8.5	239.83	40.22
473.23	9	256.91	39.93
473.20	9.5	274.08	41.68
473.19	10	291.19	42.51
473.17	11	324.99	44.28
473.15	12	357.73	45.90
473.13	13	388.93	47.71
473.00	14	418.51	48.89
472.99	15	445.81	50.16
472.98	16	471.11	51.42
472.97	17	494.48	52.66
472.95	18	516.07	54.05

472.95	19	536.01	55.04
472.94	20	554.51	56.27
472.93	21	571.68	57.14
473.16	22	587.15	58.28
473.15	23	602.13	59.44
473.14	24	616.17	60.52
473.13	25	629.37	61.54
473.13	26	641.82	62.35
473.12	27	653.60	63.30
473.12	28	664.76	64.28
473.11	29	675.36	65.29
473.11	30	685.46	66.07
473.10	31	695.10	66.73
473.10	32	704.31	67.41
473.10	33	713.13	68.10
473.10	34	721.59	68.66
473.10	35	729.72	69.23
473.09	36	737.54	69.81
473.08	37	745.08	70.40
473.08	38	752.36	71.00
473.08	39	759.39	71.61
473.08	40	766.18	72.23
473.07	41	772.76	72.87
473.07	42	779.13	73.51
473.07	43	785.31	74.16
473.06	44	791.31	74.82
473.06	45	797.14	75.50

Table XII : Thermal Conductivity of HFC-143a along the Quasi-Isotherms 498.3 K

Temperature (K)	Pressure (MPa)	Density (kg•m ⁻³)	λ (mW•m ⁻¹ •K ⁻¹)
499.02	.1	2.03	34.95
499.01	.5	10.26	35.11
499.01	1	20.80	35.26
499.01	1.5	31.62	35.50
499.00	2	42.73	35.82
498.88	2.5	54.16	36.18
498.88	3	65.89	36.38
498.87	3.5	77.93	36.76
498.75	4	90.31	37.21
498.63	4.5	103.01	37.64
498.62	5	115.99	37.99
498.61	5.5	129.25	38.54
498.49	6	142.84	39.12
498.60	6.5	156.56	39.58
498.59	7	170.55	40.07
498.58	7.5	184.74	40.45
497.89	8	199.64	41.32
497.88	8.5	214.15	41.91
497.87	9	228.75	42.46
497.86	9.5	243.38	43.13
497.86	10	258.01	43.71
497.84	11	287.04	44.92
497.83	12	315.52	46.19
497.81	13	343.13	47.46
497.80	14	369.65	48.55
497.79	15	394.88	49.73
497.78	16	418.77	50.89
497.77	17	441.27	52.01
497.76	18	462.40	53.02

497.75	19	482.25	54.15
497.74	20	500.88	55.24
497.73	21	518.37	56.28
497.73	22	534.81	57.42
497.72	23	550.30	58.54
497.71	24	564.92	59.59
497.71	25	578.73	60.45
497.70	26	591.82	61.35
497.69	27	604.24	62.50
497.69	28	616.05	63.45
497.68	29	627.30	64.19
497.68	30	638.03	64.90
497.67	31	648.29	65.67
497.67	32	658.11	66.45
497.67	33	667.53	67.12
497.66	34	676.57	67.80
497.66	35	685.27	68.50
497.66	36	693.64	69.21
497.65	37	701.72	69.79
497.65	38	709.51	70.47
497.65	39	717.03	71.06
497.64	40	724.32	71.67
497.64	41	731.36	72.14
497.64	42	738.19	72.60
497.64	43	744.81	73.08
497.64	44	751.25	73.56
497.63	45	757.49	74.05

FIGURE CAPTIONS

Fig. 1 Relative deviations between calculated values of thermal conductivity [Eq. (3)] and experimental data at atmospheric pressure.

Fig. 2 Relative deviations of calculated values of thermal conductivity by [Eq. (3)] from experimental data at atmospheric pressure.

Fig. 3 Relative deviations between theoretical calculated values of thermal conductivity [Eq. (4), Eq. (7) and Eq. (8)] and experimental data at atmospheric pressure.

Fig. 4 Relative deviations between theoretical calculated values of viscosity [Eq. (5) and Eq. (9)] and experimental data at atmospheric pressure.

Fig. 5 The excess function of thermal conductivity along six quasi isotherms

Fig. 6 Relative deviations between the values calculated by the background equation and the experimental data of Yata et al. [12]











